SIMPA, a GRASS based tool for Hydrological Studies

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Abstract

SIMPA is the Spanish acronym meaning “Integrated System for Rainfall-Runoff Modelling” (Sistema Integrado de Modelización Precipitación-Aportación). It includes several hydrological tools developed in the Centre for Hydrographic Studies of CEDEX (Ministry of Environment of Spain) (http://www.cedex.es). It was designed to analyse spatial and temporal hydrological variables and to simulate hydrological processes based on them. Models cope with water resources, flood events or quality assessment. The system was implemented using GRASS as the GIS spatial database of the system. The whole distributed hydrological modelling is based on its commands.

SIMPA models for water resources assessment were used in the White Paper Book of Waters in Spain, for the National Water Master Plan in 2000 and in Honduras in 2003. Some other studies have also been done for flood events estimation for hydraulic designs, as in Biescas in 1996 and Badajoz in 1997. Recent developments are focused on quality hydrological models and other tools used for the implementation in Spain of the European Water Framework Directive.

Keywords: hydrology, modelling system, water resources assessment, hydrology parameterisation, flood event estimation, quality models, free software, GRASS

1 SIMPA structure and configuration

The aim of the modelling development in SIMPA is to use GRASS commands and its spatial and graphical capabilities to simulate distributed hydrologic processes. FORTRAN or C programming languages as well as OS commands are also used in shell scripts. Originally, it was implemented on HP-UX through an interface developed with XGEN. Nowadays, SIMPA 4.0 works on Red Hat 9 Linux OS, kernel 2.4.20. (http://www.redhat.com/); the graphical interface is programmed in Tcl/Tk language (Tcl/Tk 8.3.5 libraries included in OS Red Hat Linux). Compilers used are gcc 3.2.2 and Intel Fortran Compiler for Linux, non commercial version 8.0.034 (http://www.intel.com/software/products/compilers/flin/noncom.htm). Vtcl 1.6.0b2 (Visual Tcl) is the visual interface for programming Tcl/Tk. http://vtcl.sourceforge.net/. Next graph tries to describe SIMPA’s structure. The interface is programmed in Tcl/Tk helped by Visual Tcl. It can execute GRASS commands directly or by means of shell scripts. The latter are compose by GRASS commands and programmes FORTRAN or C languages. In the past, SIMPA visual interface was developed in XGEN. New LINUX versions doesn’t allow the installation of XGEN in a full free software environment because its dependence from OSF/MOTIF , so it was decided to work with Tcltkl as the GRASS interface (figure 1).

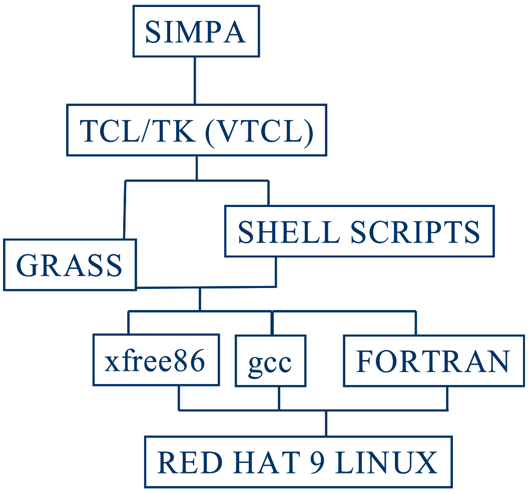

Figure 1 SIMPA structure

Concening the temporal hydrological data, there is an interchange with CEDEX's HIDRO database (Quintas, 1996). Usually, basic temporal data have been colleted by different Organisations in the meteorological and hydrological monitoring networks with different time steps. These data are classified considering the different types of variables recorded and their location among other information. HIDRO database contains information for several hydrological purposes and exports time series in ASCII ffiles readable by SIMPA modules. LEMA is the name of file format for any monthly data in a set of monitoring stations (figure 2). Every station should have geographical coordinates and a unique code of three letters to distinguish the different kind of variables, in order to permit spatial operations, i.e. interpolation, maps of distributed variables, etc. This format is suitable for monthly or yearly simulations of water resources and water quality assessments.

```
1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901

  606695  4792990 01010-U PMT 1979-80  -100.0  -100.0  -100.0  -100.0   105.4   280.4    43.4   358.0   121.0   104.9    68.0    73.2  -100.0
  606695  4792990 01010-U PMT 1980-81   463.2   227.3  -100.0  -100.0  -100.0  -100.0   142.9   135.1    72.7   116.6    41.5   113.3  -100.0
  606695  4792990 01010-U PMT 1981-82   287.2    69.8  -100.0   191.8   213.6   346.6     5.0    68.8   126.4    53.4   153.1    42.5  -100.0
  606695  4792990 01010-U PMT 1982-83   435.6   241.2   392.0    89.4   263.5   216.2  -100.0  -100.0  -100.0  -100.0  -100.0  -100.0  -100.0
  606695  4792990 01010-U PMT 1983-84  -100.0  -100.0  -100.0  -100.0  -100.0   145.9    77.5   257.7    61.3    12.6    67.6   261.8  -100.0
  606695  4792990 01010-U PMT 1984-85   121.7   259.0   188.5   180.2    72.3   259.4   112.6   333.2    71.3    42.5   120.0     4.5  1765.2
  606695  4792990 01010-U PMT 1985-86    66.9   147.0   111.4   497.8   160.1   212.1   372.3    62.8    84.5    49.1    82.6   172.7  2019.3
  606695  4792990 01010-U PMT 1986-87   120.7   212.7   311.2   183.4   252.8   150.9   122.4    83.6   141.2    80.1    60.0    33.6  1752.6
  606695  4792990 01010-U PMT 1987-88   216.2   331.6    61.4   436.4   226.8   241.7   171.5    95.8   160.0    94.6    62.0    20.8  2118.8
  606695  4792990 01010-U PMT 1988-89    42.1    36.5   137.3    53.5   260.3   101.2   362.0    43.3    42.6    79.4    59.7   108.4  1326.3
  606695  4792990 01010-U PMT 1989-90    52.8   181.0    32.6   132.9   129.1    56.9   423.3   119.0    98.8    60.1    50.0   155.6  1492.1
  606695  4792990 01010-U PMT 1990-91   185.3   284.3   298.4    89.1    96.2   186.7   292.2   247.0    69.3    86.8    62.9   251.8  2150.0
  606695  4792990 01010-U PMT 1991-92   117.9   356.0    55.3    88.7    46.2   239.5   243.5   115.0   202.1   152.2   165.2   173.9  1955.5
  606695  4792990 01010-U PMT 1992-93   492.8   197.6   252.9    18.2    62.6    64.7   232.7    97.5   107.2   154.0   102.5   237.5  2020.2
  606695  4792990 01010-U PMT 1993-94   183.4    91.8   344.8   190.3   285.9    95.4   447.4   124.7   146.6    33.6    53.7   246.3  2243.9
  606695  4792990 01010-U PMT 1994-95   178.3   100.3   249.7   300.1   183.1   261.9    68.4   125.9    19.4    73.6    79.0   179.0  1818.7
  606695  4792990 01010-U PMT 1995-96    22.0    81.0   207.1   114.6   316.9   104.0    89.1   112.4    69.9   126.4   142.3   132.3  1518.0
  606695  4792990 01010-U PMT 1996-97   152.2   462.2   196.0   212.3    55.1    43.7    86.8   159.1   218.6   196.2   219.5    61.3  2063.0
  606695  4792990 01010-U PMT 1997-98   109.9   326.9   230.5    92.3    56.4   121.9   256.4  -100.0  -100.0  -100.0  -100.0  -100.0  -100.0
  606445  4793200 01010-V PMT 1985-86    19.3    56.6    55.5  -100.0  -100.0    52.2   213.6     6.6    42.7    11.2    41.3    69.5  -100.0
  606445  4793200 01010-V PMT 1986-87     9.9    73.9   164.5   111.8   177.4    67.6    16.7    12.1    65.9    41.5     8.6    10.6   760.5
  606445  4793200 01010-V PMT 1987-88    23.2    57.8     2.9   227.3   175.7    21.4    56.2    34.4    36.7    41.3     8.7    20.8   706.4
  606445  4793200 01010-V PMT 1988-89     5.1     3.1    24.5     9.2   101.6    22.7   222.9    16.0    11.1    51.6    25.8    22.4   516.0
  606445  4793200 01010-V PMT 1989-90     4.7    96.2     2.3    89.6    88.5     6.6   364.0    21.8    20.3     8.4    18.9    52.9   774.2
  606445  4793200 01010-V PMT 1990-91    42.2   104.6   120.5    29.7    15.9   113.0   168.8   218.2    25.8  -100.0    24.0   126.5  -100.0
  606445  4793200 01010-V PMT 1991-92    58.5   401.2     8.6    30.0     8.0   157.1   195.5    79.2   167.8   128.4   146.0   154.0  1534.3
  606445  4793200 01010-V PMT 1992-93   460.0   167.0   236.0    13.0    71.8    40.5   202.5    85.5    85.5   130.5    77.0   192.5  1761.8
  606445  4793200 01010-V PMT 1993-94   148.5    75.5   323.0   166.5   262.0    63.8   429.5   110.0   130.0    26.0    47.5   215.5  1997.8
  606445  4793200 01010-V PMT 1994-95  -100.0   113.0   226.0   278.5   173.0   187.5    63.0   108.5    17.5    65.0    54.5   147.5  -100.0
  606445  4793200 01010-V PMT 1995-96     7.0    64.5   179.0   112.0   274.5    99.5    64.5   111.0    70.0   119.5   143.5    98.0  1343.0
  606445  4793200 01010-V PMT 1996-97   147.5   456.0   185.5   183.0    40.0    51.5    87.0   157.5   214.5   175.0   230.0    73.0  2000.5
  606445  4793200 01010-V PMT 1997-98    60.0   351.0   231.0    97.0    56.0  -100.0  -100.0  -100.0  -100.0  -100.0  -100.0  -100.0  -100.0
  605205  4788955 01011-I PMT 1979-80  -100.0  -100.0  -100.0   120.3   101.6   298.6    39.7   287.2   124.2    85.1    63.0    69.9  -100.0
  605205  4788955 01011-I PMT 1980-81   447.1   239.6   372.0  -100.0   195.1    85.4  -100.0  -100.0  -100.0  -100.0  -100.0  -100.0  -100.0
  605205  4788955 01011-I PMT 1981-82  -100.0  -100.0  -100.0  -100.0  -100.0  -100.0     3.1    58.0    94.9    41.6  -100.0  -100.0  -100.0
  605205  4788955 01011-I PMT 1983-84  -100.0  -100.0  -100.0  -100.0   282.4   164.8    87.1   298.3    69.7    10.1    79.4   240.3  -100.0
  605205  4788955 01011-I PMT 1984-85   134.1   256.1   165.7   163.7    79.7   254.6    82.4   271.1    61.8    54.2   102.7     6.3  1632.4
  605205  4788955 01011-I PMT 1985-86    57.4   131.8   100.2   441.3   123.8   167.0  -100.0    53.7    75.6    43.6    56.8   117.5  -100.0
```

Figure 2 Fields and positions in a LEMA format file. First line for positions.

Other time steps are also used by SIMPA models. The format adopted for variable time step data has been selected according to the standard used in Spain in the Hydrological Flood Prevention Systems (SAIH) installed in several River Basin Authorities sites as flood alert monitoring networks. These files (figure 3) include all variables needed to study a whole event in a unique data file. The time series recorded in a station are written in each line where a code in the first position identifies the kind of variable, i.e. P for rainfall, Q for flows, etc. The header contains information about time steps and total number of data.

```
* CONFEDERACION HIDROGRAFICA
* Sistema Automático de Información Hidrológica. Fichero estándar de intercambio.
*
* Intervalo de fechas  :    22/10/2000 03:40   hasta  23/10/2000 16:00
* Incremento de tiempo :     30 min
* Número de Intervalos :   437
* Datos en mm. por intervalo para pluviometros.
* Datos en m. al final del intervalo para niveles de embalse.
* Datos en m3/s al final del intervalo para caudales desembalsados.
* Coordenadas XYZ UTM (huso 30) aproximadas.
*
G 437     50
*
P "CONTRERAS 1              " 610305 4422280   15 0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
P "CONTRERAS2               " 611040 4397680  382 0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
P "CONTRERAS3               " 622370 4401180   37 0.0     0.0     0.0     0.4     0.2     0.2     0.0     0.0     0.0
P "CONTRERAS4               " 623850 4392140   62 0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
P "CONTRERAS5               " 622215 4389800  438 0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
P "CONTRERAS6               " 628635 4376645  112 0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
P "CONTRERAS7               " 617010 4399955   63 0.0     0.0     0.0     0.0     0.0     1.0     6.4     0.6     0.6
P "CONTRERAS8               " 628460 4378410  151 0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
Q "RAMBLA_POYO              " 671000 4436000  112 0.0    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
```

Figure 3 Fields and positions in a SAIH format file

Spatial data in SIMPA are organized using GRASS structure. So, location and mapsets have to be defined. Two mapsets are required: one for the basic spatial data needed in the project and a second one for reading and writing temporal data and modelling results.

SIMPA is currently implemented on a PC with two partitions in the hard disk: one with the LINUX OS and the SIMPA model, and the other with Windows XP so that end users not used to LINUX can feel comfortable for other works. All the developments are done under LINUX OS, but considering SIMPA end users, there is the project of compiling the whole application in a LINUX emulator for Windows such as CYGWIN.

2 Modules in SIMPA

The whole application has been implemented in a modular way so that it is very easy to add new modules with new capabilities. For the practical hydrological purposes six main modules have been developed. They gather tools for extraction and analysis of information, and for the simulation of hydrological processes. So, modules for maps display, graphs and analysis of temporal series, parameterization and basin delineation from DEM, water resources assessment and flood event estimation have been implemented. Water quality modules are in progress. In the main menu of SIMPA (figure 4), the access to the different modules is organised in the left column window. The top window is devoted to credits and in the central one is located the GRASS monitor.

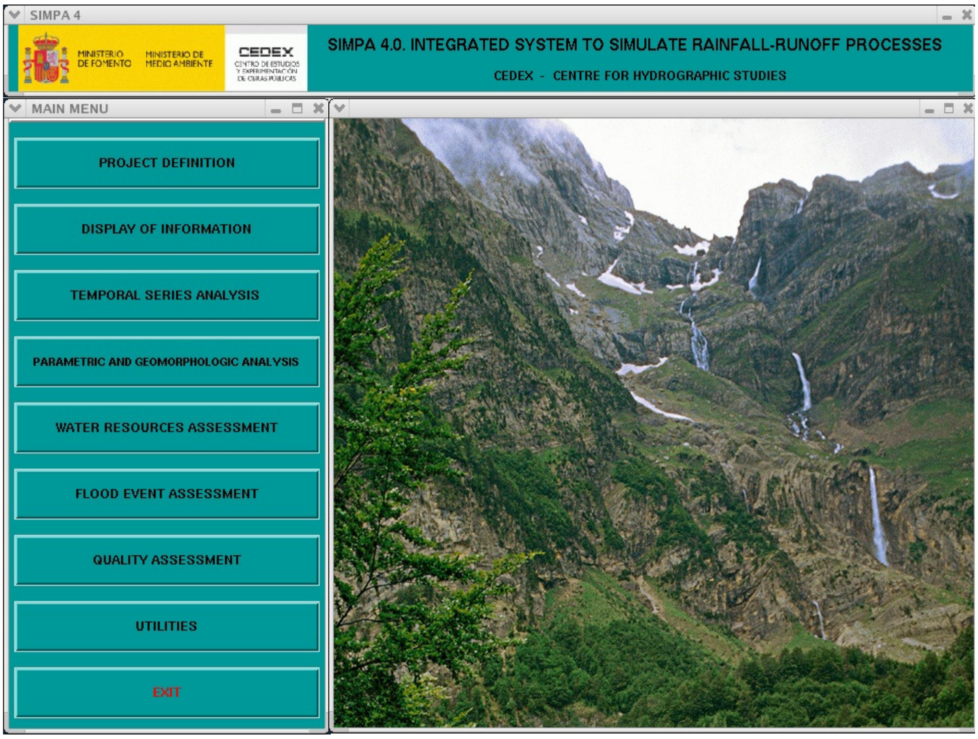

Figure 4. SIMPA's main menu

2.1 Display of Information

This module is very useful for describing and analysing spatial and temporal data and simulation results. The information an be display by means of several tools, such as multiple windows for the display of different layers of information (figure 5), zooms, check of map values selection of colours or palettes. GRASS commands as d.rast, d.vect., r.colors, d.legend , d.graph or d.text are directly used for these purposes. A special sub-module was prepared to show defined collation of simulated maps and graphs.

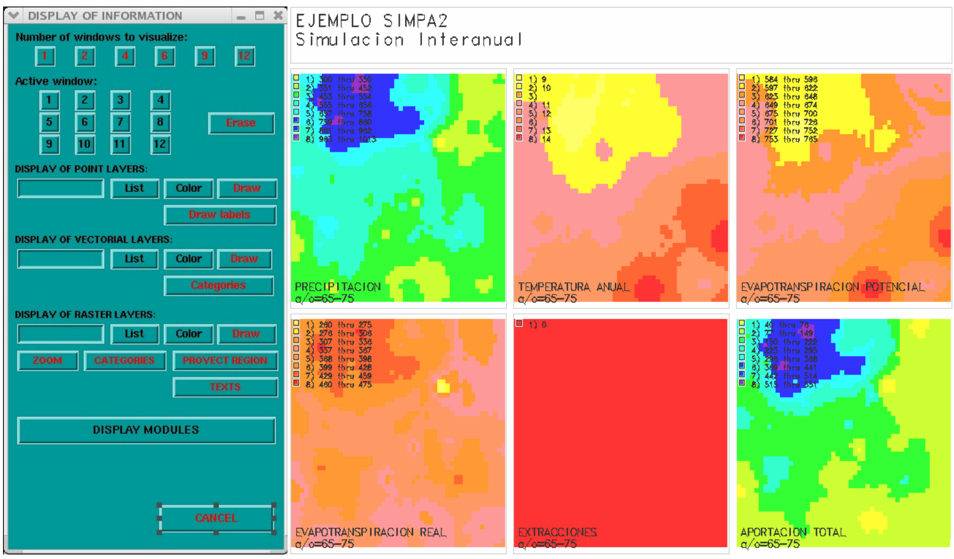

Figure 5. Interface to display GIS information and a collation of simulation results

Some difficulties were found to produce and change palettes and legends because of the limitations of some GRASS commands. Usually, legends are shown by means of a continuous gradation of colours, what makes difficult to highlight certain ranges of values. Other options used are based on reclassifications (r.reclass). But none of these options are really interactive and immediate; this is a bug for analysing spatial data in a comfortable way.

2.2 Temporal Series Analysis Module.

This module facilitates the analysis of temporal series recorded in hydrometeorological stations (figure 6). A LEMA file should be selected at the top of the window and easy operations can be done to edit it, to show spatial locations of the set of stations contained in the LEMA file, to calculate basic statistics of the time series recorded in each station and to draw chronograms of them.

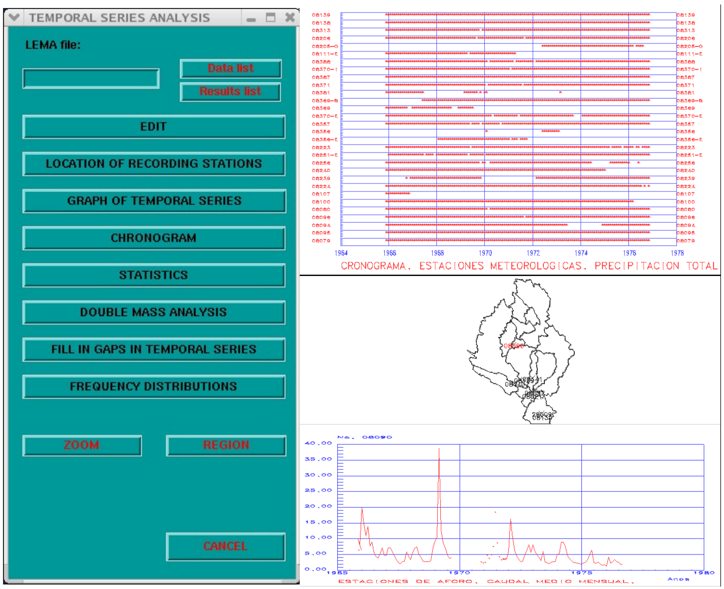

Figure 6. Main interface to temporal module, chrnograms and a display of a temporal evolution

Double mass analysis, as well as the ellipse test and residual evolution graph (figure 7), are used to analyse the homogeneity of the time series. These exercises are done considering reference series, i.e. series from another station or from the mean values of the stations included in the LEMA file.

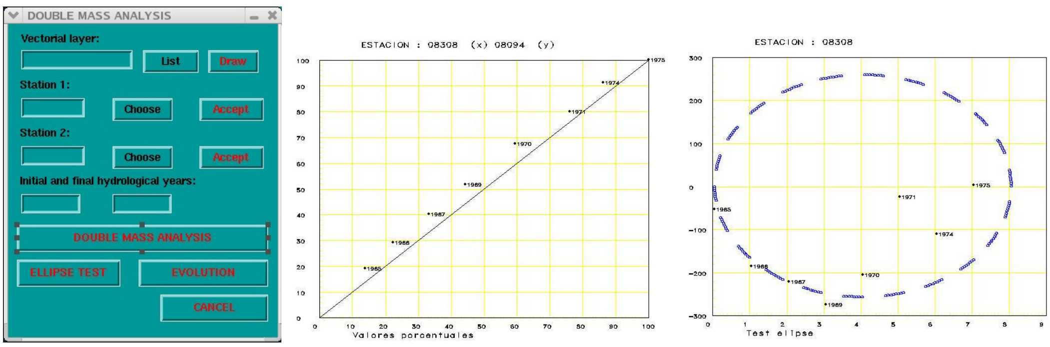

Figure 7. Double mass analysis and ellipse test

Gaps in temporal meteorological series can also be filled in through a multivariate regression analysis. This technique, known as CORMUL, works in a similar way as those implemented in HEC-4 package (U.S. Army Corps of Engineers).

Frequency distribution performance can be done with different theoretical distributions. Parametric or non parametric options are available as well as different log transformations and graphical positions, as normal or Gumbel (figure 8).

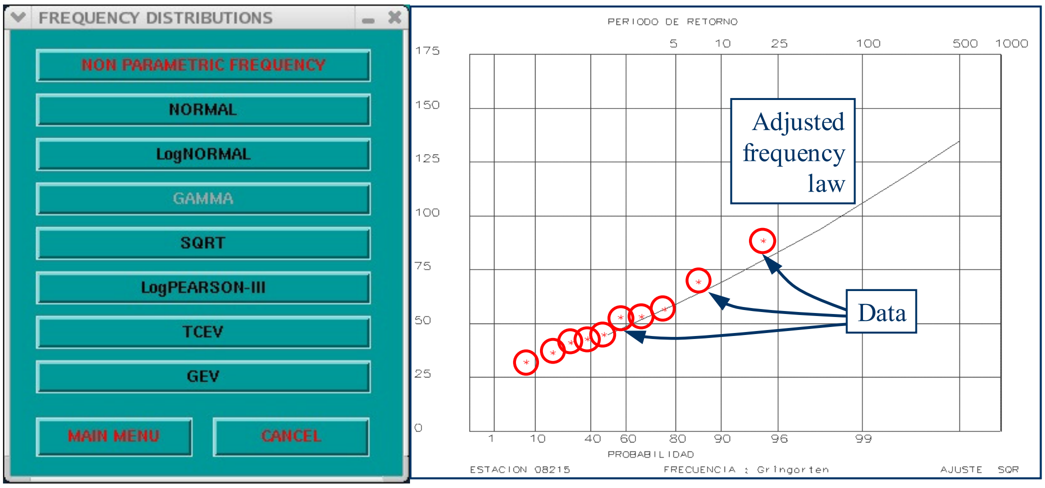

Figure 8. Frequency studies

A specific software was developed to use the GRASS command d.graph. Actually graphs are not interactive and data can not be checked once drawn because of the limitations of this command. Till now zooms on data drawn are not allowed either.

2.3 Parameterisation and Basin Delineation

The parameterisation and characterization of the main hydrographic features in the basin is a very important issue in hydrological studies. The laws of the hydrological models depend on certain parameters that are also related with the physical characteristics of the territory. Some of them are functions of specific characteristics while others are estimated through weighted combinations of parameters. This works can be helped with direct GRASS commands, even those developed with hydrologic purpose, or sometimes solved by FORTRAN programs, once maps has been exported from the GRASS format to ASCII matrixes in files. This module assists the parameterisation and calculation of:

- Mean areal values of raster variables in basins
- Reclassification procedures and linear parametric modelling
- Edition of raster layers allowing the change of values selected by their category or included in a specific region
- Curve number model from land uses knowledge (figure 9), soil textures and slopes according to the Spanish drainage regulations
- Estimation of hydrological parameters for shallow and deep groundwater assessment
- Runoff split into surface and groundwater
- Residence times in shallow and deep layers

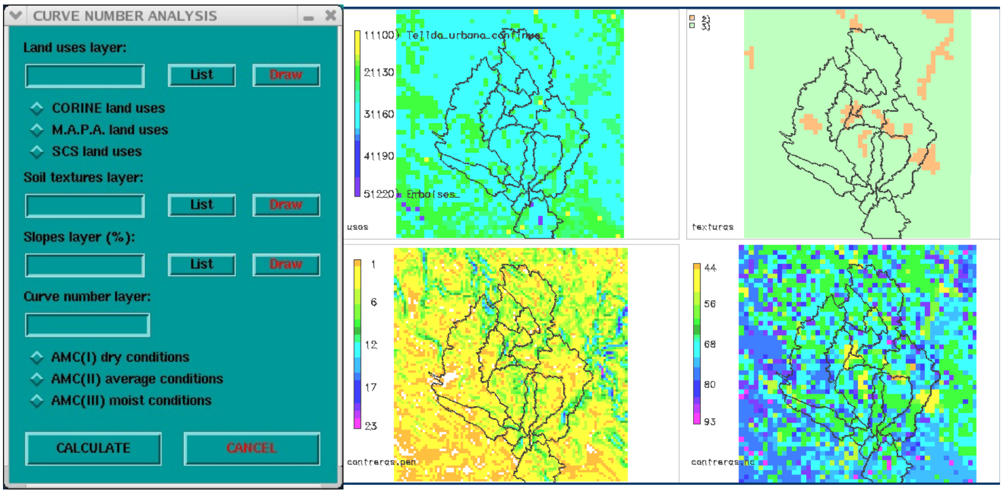

Figure 9. Curve number sub-module as used with available Spanish data.

Most of the former reclassification operations are based on hydrologic knowledge rules and on the local data availability. Programs mainly use GRASS commands directly as r.reclass. The advantage of the implemented rules is to avoid repetitions and the availability of a friendly and comprehensive interface.

The way to extract information from DEMs is by means of FORTRAN programs. DEMs are very useful for hydrographic studies and many other derived digital models can be obtained from them. Examples implemented in SIMPA are: slopes maps, drainage directions maps, cumulative drainage networks, draining basin delimitation to a particular cell, river network classifications, main channel delineation, centroids, hypsometric curves (figure 10) and geomorphologic parameters associated to the previous basin, and unit hydrographs (IUH) (figure 11). The definition of the initial cells for a drainage network calculation is a hydrologic issue that has been simplified in SIMPA using a minimum area criterion.

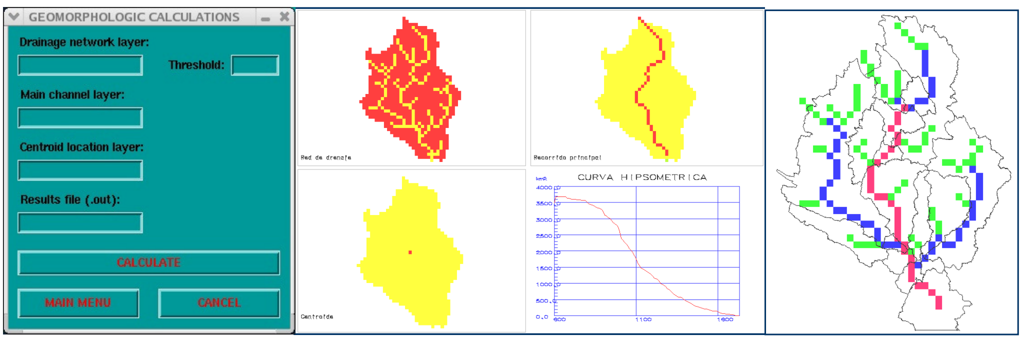

Figure 10. Hypsometric curve, drainage network, centroid location and a Horton-Strahler classification of river branches

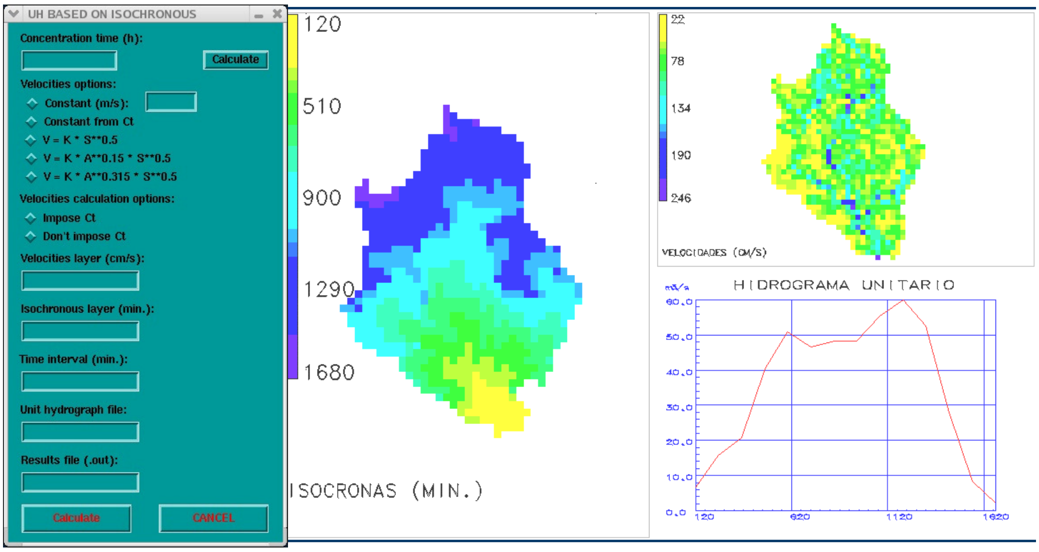

Figure 11. Unit hydrograph estimation by means of isochrones and runoff velocities

2.4 Water Resources Assessment

The objective of the water resources assessment modules are the simulation of the hydrological cycle and the estimation of the main variables involved. The core module was developed at a monthly step (Estrela and Quintas, 1996; Ruiz, 2002) with a quasi-distributed model. It is an implementation of a classic soil moisture balance model, Témez (1977), in a distributed way and its results for a natural cycle are useful for planning assessment (figure 12). Two kind of storages are considered, soil and aquifer, and a collation of transfer laws depending on different parameters such as maximum soil storage, maximum infiltration capacity or the aquifer discharge coefficient are taken into account.

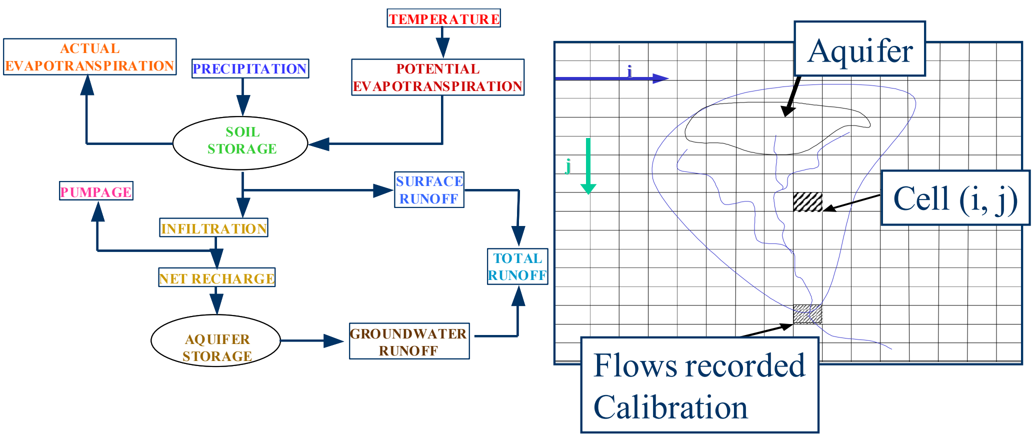

Figure 12. Variables and flows simulated in the monthly model

The interannual water balance model applies a unique water balance equation to the rainfall and the potential evapotranspiration in order to estimate actual evapotranspiration and runoff for the mean annual period. The annual water balance model applies the same simplified balance equation in a yearly step. Modules are structured in a similar way:

1. Rainfall, temperature and water abstractions are evaluated by means of an inverse distance interpolation technique. The interpolation is applied to the data or to residuals after an estimation of mean patterns in the considered time step.

2. Potential evapotranspiration is estimated by means of experimental methodologies as Thornthwaite's or Hargreaves' and monthly regression coefficients can be applied to adapt it to other physically based methodologies.Actual evapotranspiration and runoff are estimated in the interannual and annual modules using Turc-Pike or Budyko equations. The monthly continuous model allows the estimation of the actual evapotranspiration, recharge, groundwater discharge, surface runoff and total runoff, and soil and aquifer water storage using Témez equations (figure 13).

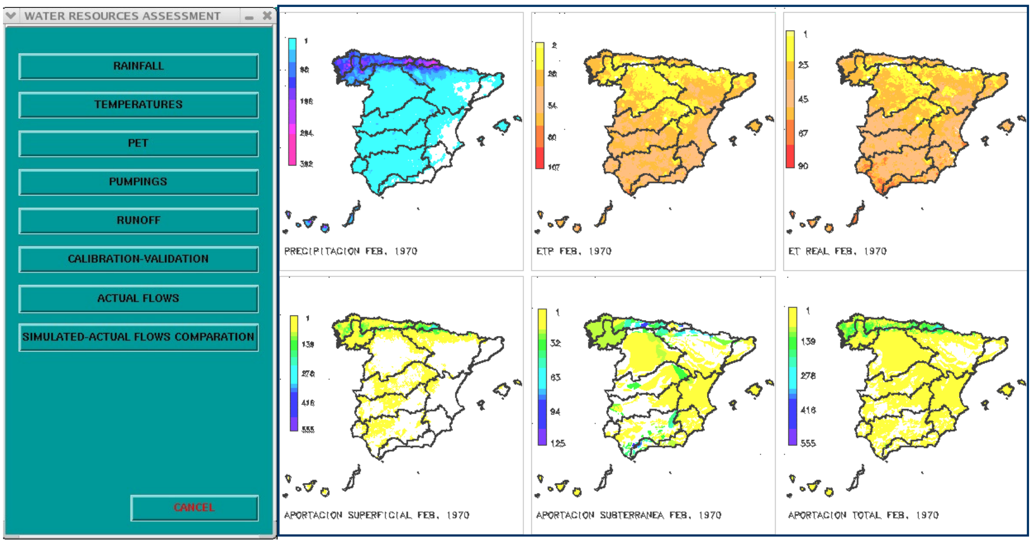

Figure 13. Variables simulated at a monthly step

3. The graphical display helps the user to calibrate and validate the processes. As mentioned previously, programs in C and FORTRAN language were developed for this purposes. Series of simulated and observed flows at a monthly and annual time step can be checked (figure 14) as well as errors and dispersion graphs for rainfall and runoff series.

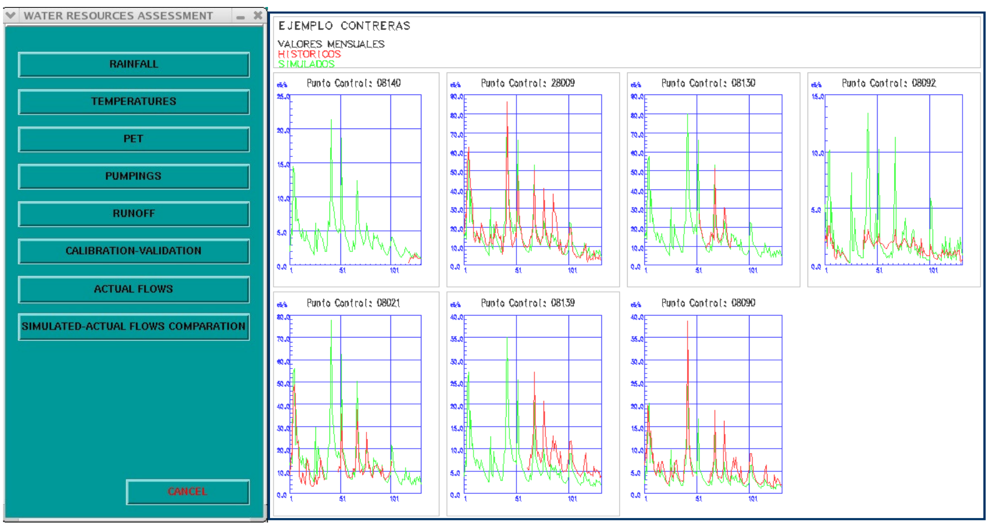

Figure 14. Monthly series of simulated and observed flows

Recently it was initiated the implementation of modules to interpolate actual flows over the drainage network. Its comparison with accumulated runoff may be useful for an impact assessment. Two possibilities are being implemented: potential functions between area and flows and inverse incremental area to the outlet of each subsystem defined by each set of stations comprising a drainage network without anymore data available.

2.5 Flood event estimation

Some tools for flood event studies have been already introduced in the parameterisation modules, as the information extraction from DEMs (IUH). These results can be combined with hyetographs and propagation rules as the classic HEC-1 or HMS models do.

Besides the derivation of the IUH, there are other methodologies implemented in SIMPA for flood event estimation: modules where developed to implement a revision of the rational method, widely used in Spain for drainage works. Input data should be given as distributed layers of physical and meteorological maps characterizing the generation of maximum flows (figure 15).

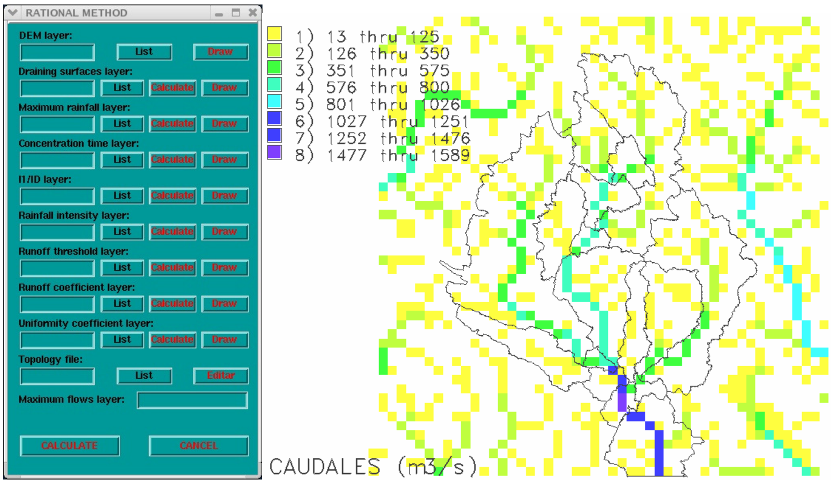

Figure 15. Rational methodology menu and results

Some intermediate results can be highlighted because of their importance. Maps of mean areal maximum rainfall, concentration time and distances to the outlet of each drainage basin and slopes of the principal branch are obtained taking into account drainage directions and the resolution of each cell (figure 16).

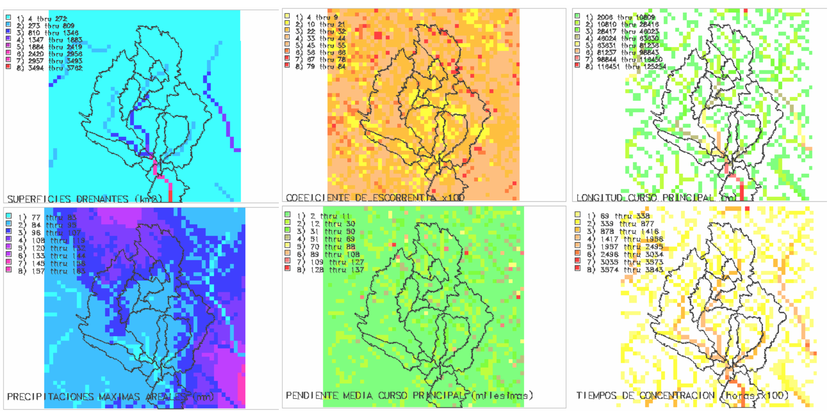

Figure 16. Drainage area, mean areal maximum rainfall, runoff coefficient, slope and distances of the main branch and time of concentration (from left to right and top to bottom)

The distributed models for flood event estimation in SIMPA consider independently runoff generation, propagation and base flow. Runoff generation uses the runoff threshold of the U. S. Soil Conservation Service model. For unchannelized flows, a recession coefficient is applied, as well as for the base flow. Channelized flows are estimated using isochrones field or other hypothesis on velocities. Nowadays, the University of Valencia is working on a model that considers several storages and propagation formulation based on a cinematic wave and geomorphologic formulations.

2.6 Quality assessment

This module is currently in progress. Its main objective is the implementation of PolFlow model (de Wit, 2001) for diffuse pollution at a river basin scale. The model was developed with conceptual formulas to be applied in large basins and periods lasting more than five years. Parameters needed as residence time (figure 17) or coefficient for runoff repartition are nowadays implemented, but the model is not working yet.

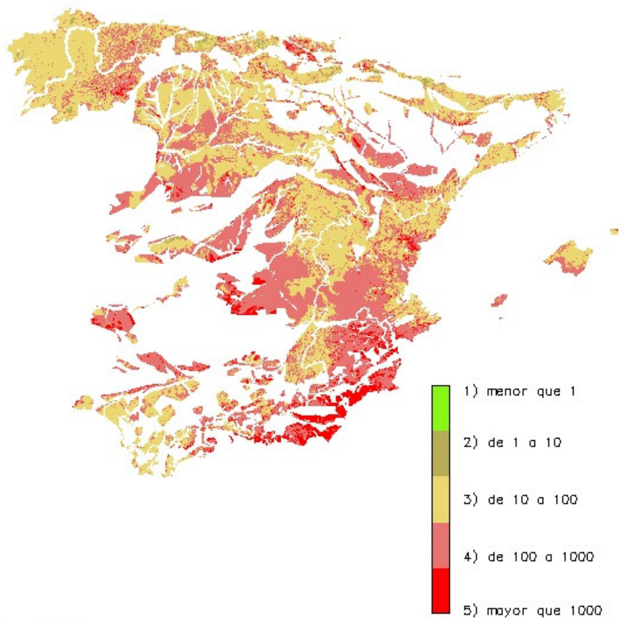

Figure 17. Maps of residence time for deep recharge

3 Case Studies

SIMPA is used in CEDEX for many purposes. Four cases have been chosen because of their importance for this paper, two related with water resources assessment and two related with flood events estimation.

a) Spanish water resources evaluation in natural regime.

Monthly maps of rainfall, actual and potential evapotranspiration, recharge, water storage in the soil and groundwater, direct and total runoff from October 1940 to September 1996 (figure 18) were obtained for the whole country. Maps resolution was 1 km^2. A selection of river gauging station near to the natural regime were selected for calibration and validation.

The results were used for a Spanish hydrological characterization published in the Water White Paper Book (Ministry of Environment, 2000) translated to English this year (Ministry of Environment, 2004). A comparison of these natural resources, hydraulic infrastructure and demands was carried out specifically for the National Water Master Plan of Spain (Ministry of Environment, 2002): flow series were simulated in SIMPA for water guarantee assessment and a evaluation of the possibility of river transfers to satisfy Spanish demands.

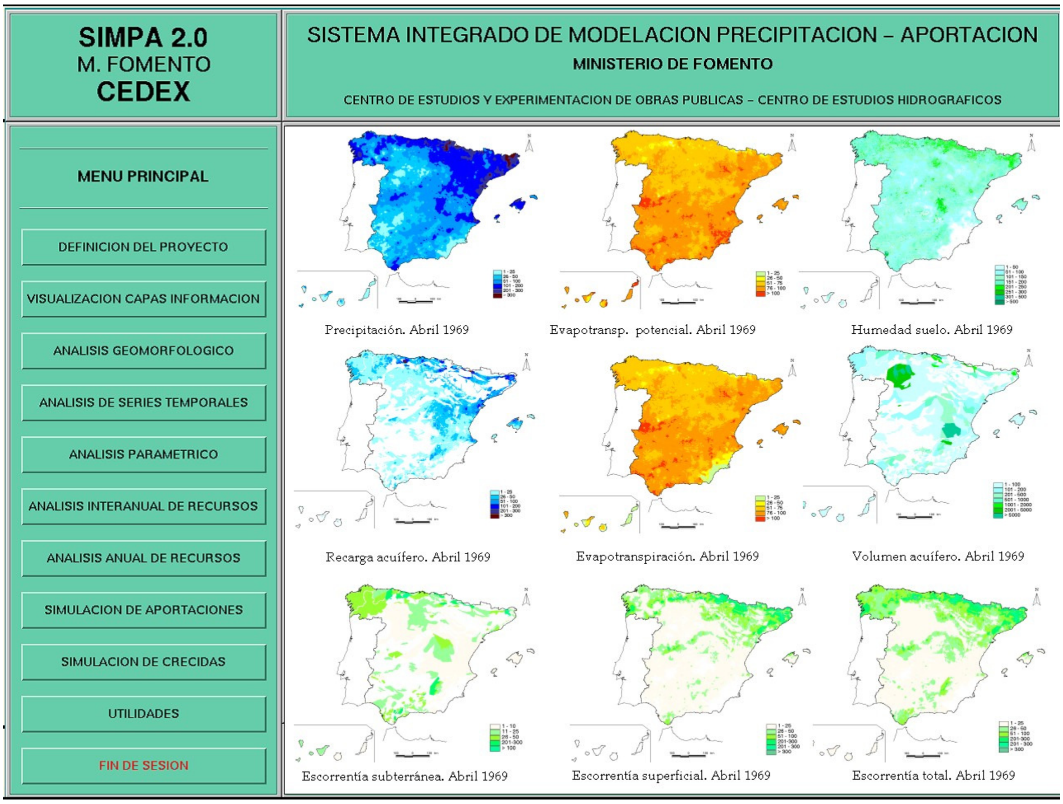

Figure 18. Sequence of variables simulated in monthly step. Old version of SIMPA interface on HPUX.

b) Water balance in Honduras (Central America)

A water balance was carried out in Honduras (Balairon et al., 2003) considering water resources and water demands. Water resources were simulated from May 1970 to April 2002 (figure 19). Mean annual demands were also managed in a distributed way, varying within a year in a monthly step. Taking into consideration the demand evolution, two different scenarios, 2003 and 2020, were considered. Results were the spatial distribution of water balances and consumption indexes. This study was financed by the Spanish Agency for the International Cooperation (AECI) in the framework of an aid programme for the Environmental Administration of Honduras (Secretaría de Recursos Naturales y Ambiente-SERNA).

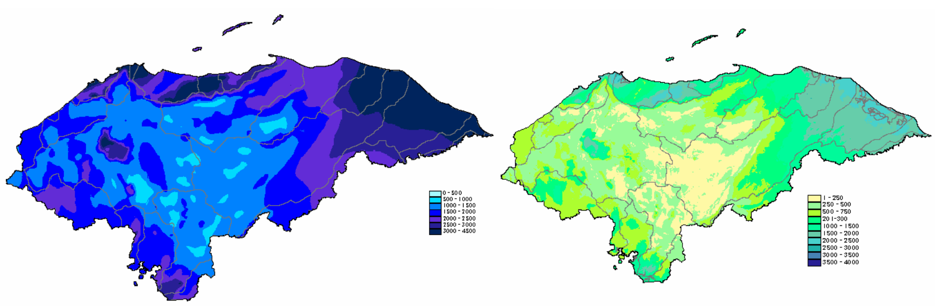

Figure 19. Rainfall and runoff simulated in Honduras (mm/year). 1970/71-2001/02

c) Flash flood in Biescas (Spain)

The catastrophic flood in Biescas happened in August 1996 and caused 83 victims in a camping near the river Arás (figure 20). The hydrogram was estimated using the flood event modules of SIMPA (figure 21).

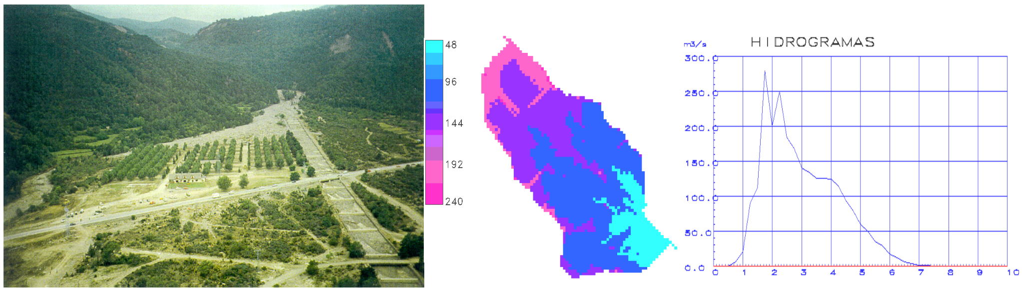

Figure 20. View of affected area. Camping location close to a river chanelisation. Isochrones field and simulated hydrogram in Biescas 1996

d) Flash flood in Badajoz (Spain)

In November 1997 a flash flood caused 13 victims in the city of Badajoz (figure 22). This flood was also simulated with SIMPA (figure 23).

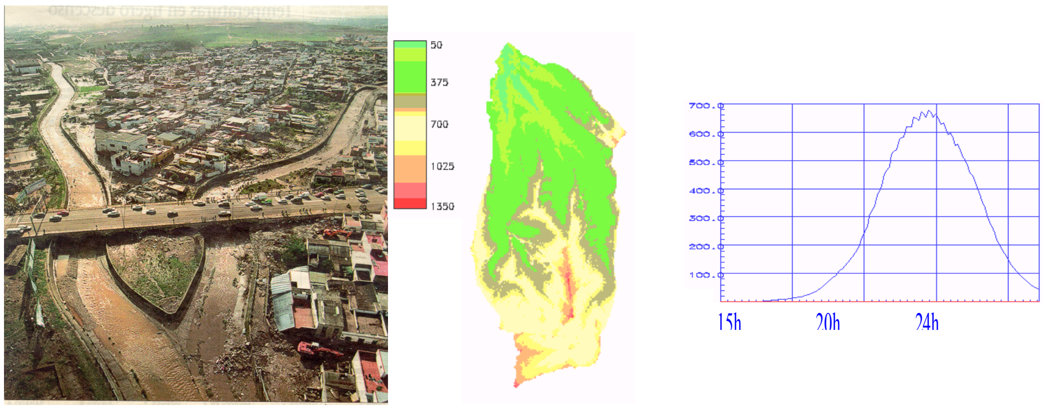

Figure 21. Area mainly affected by the flood in Badajoz. Isochrones fields and simulated hydrogram in Badajoz

4 Conclusions

A hydrologic system developed on GRASS and other free software has been described. SIMPA is not only a graphical interface working on GRASS commands, but it also integrates hydrological models simulating continuous phases of the hydrologic cycle. Water resources, flood event estimation and water quality are the three main topics. GRASS offers a suitable structure for distributed hydrological modelling. Shell scripts, VTcl, Tcl/Tk, GRASS, C and FORTRAN programs have been used in its development. So, GRASS is a suitable and a highly appreciated tool for hydrologic modelling. Anyway, some limitations were found for the map analysis and display in the use of commands as d.graph and d.legend in order to obtain an interactive an comfortable operation in several modules. VTcl is the graphical tool used instead of XGEN (the first version tool) because of its compilation problems.

5 References

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